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REMOTE (VHR) SENSING IMAGERY M. Kuffer1, K. Pfeffer, I.S.A. Baud,
R. Sliuzas

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ANALYSING SUB-STANDARD AREAS USING HIGH RESOLUTION REMOTE (VHR) SENSING IMAGERY

CASE STUDY OF MUMBAI, INDIA

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ABSTRACT (Max. 300 words):

Urban planners and managers in developing countries often lack information on sub-standard areas. Base data mostly refer to relatively large and heterogeneous areas such as census or administrative wards, which are not necessarily a relevant geographical unit for representing and analysing deprivations. Moreover sub-standard areas are diverse, ranging from unrecognized slum areas (often in the proximity of hazardous areas) to regularized areas with poor basic services, and information on this diversity is difficult to capture. Sub-standard areas in Indian cities are typical examples of that diversity. In Mumbai, sub-standard areas range from unrecognized slum pockets to large regularized sub-standard areas.

This paper explores the usage of the latest generation of very high (spatial and spectral) resolution satellite images using 8-Band images of WorldView-2 to analyse spatial characteristics of sub-standard areas. The research illustrates how VHR imagery helps in rapidly extracting spatial information on sub-standard areas as well as provides a better understanding of their morphological characteristics (e.g. built-up density, greenness and shape). For this study an East-West cross-section of Mumbai (India) was selected, which is strongly dominated by a variety of sub-standard areas. The research employed image segmentation to extract building footprints and used texture and spatial metrics to analyse physical characteristics of sub-standard areas, combined with purposely-collected ground-truth information. The results show the capacity of this methodology for characterizing the diversity of sub-standard areas in Mumbai, providing strategic information for urban management.

KEY WORDS

Sub-standard areas; remote sensing; very high resolution imagery

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INTRODUCTION

Local and regional authorities regularly produce development frameworks to strategically direct urban and regional development, with a variety of spatial plans derived from them at more disaggregated levels. To make such Plans useful in planning processes, a variety of data and knowledge sources are required, reflecting the complexity of the city forms (or urbanism), and the variety of administrative regimes under which city areas resort. In developing countries especially the emergence and growth of sub-standard settlements[1] differing in their physical layout and services, socio-economic stratification as well as their legal rights (authorized versus unauthorized) need to be recognized. Currently, bringing together and integrating information on urban developments is a very labour-intensive process, requiring creativity and intensive knowledge of a city, as the process of preparing the new Master Plan in Mumbai illustrates. Especially finding reliable information on various types of sub-standard areas of various classifications for cities as a whole is a vexed problem. Until now, not much research has been done to quantify the specific morphological characteristics of the diverse sub-standard areas to be able to identify these areas within the city boundaries. First attempts include the study by Taubenböck and Kraff (2013) focusing on morphological characteristics of slums (using size, density, height and distance between buildings) while analysing the homogeneity between slum areas and their heterogeneity compared to formally built-up areas.

In this paper we explore the potential of new sources of information on such city complexity in Mumbai, focusing on the extent to which very high resolution remote sensing imagery can identify different types of sub-standard areas, providing spatially disaggregated data in a more timely fashion for urban planning processes. Our earlier research provided a disaggregated mapping of multiple deprivations experienced within the Mumbai area at the level of the health wards (of which there were 88 at the time of the 2001 Census) (Baud, Pfeffer, Sridharan, & Nainan, 2009). The limitations of that study lay in the size of the health wards, which on average had a population of 136,000. The heterogeneity within health wards could not be analysed, nor the clustering of deprivations across health ward boundaries. To overcome that limitation, we utilized very high resolution (VHR) imagery to identify the heterogeneity of sub-standard urban settlements using visual image interpretation in a study of Delhi, based on their spatial characteristics, e.g. high densities, absence of access road infrastructure and open spaces (Baud, Kuffer, Pfeffer, Sliuzas, & Karuppannan, 2010). In this paper, we propose a similar analysis for Mumbai, exploring whether there are quantifiable differences between formal and sub-standard areas as well as between types of sub-standard areas, so that such areas can be automatically extract from an image. The study goes further than the earlier study in terms of the classification criteria used, because of the quantifying morphological characteristics as well as in terms of the type of satellite image (using higher resolution images) and the algorithm employed.

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[1] While many policy documents, both nationally and internationally, use the term 'slums' to refer to deprived areas with poor living conditions, we prefer the term 'sub-standard settlement', because in India slum definitions very across states and authorities, and slum declaration is very much a political process. We consider sub-standard settlements are more neutral and inclusive term covering the full range of areas facing physical and other deprivations.

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INFORMATION GAP ON SUB-STANDARD AREAS

Sub-standard settlements are residential areas which are physically deprived in terms of the housing structure, availability of basic services such as water, sewage and sanitation and presence of open space, if not other aspects. Apart from their morphology, such settlements differ in their legal status, historic trajectories, and spatial use, as well as in the composition of their population in terms of profession, origin, culture, social class and religion. Residents of sub-standard settlements also suffer from lack of access to resources in other livelihood capitals, such as lack of access to education, employment or banking services, and social discrimination, to name a few. Morphologically, housing densities in combination with patch size, spatial arrangement of houses and paths and presence of open and green space is a first set of indicators. Furthermore, some settlements are residential areas, while others combine economic productivity with residential use. Depending on the typical economic activity (pottery, sewing, waste recycling etc.), houses may display particular spatial structures and arrangements, such as a combination of smaller and larger houses. Residential sub-standard settlements without economic activity are often located closely to sites of economic production and jobs. Almost all settlement have some kiosks inside the settlement on the street-facing housing row. However, specific city histories have to be taken into account in doing such morphological analysis. Mumbai has a rich historical development and because it is built on a peninsula, with heterogeneous topography and limited space, housing densities are extremely high and do not necessarily indicate sub-standard areas across the board.

To date insufficient information is available about the amount, extend and location of such sub-standard areas in Indian cities. The same holds for Mumbai where actors involved in the design of the current city development plan are facing a lack of information on sub-standard settlements in terms of location, extent, but also nature (pers. comm). A further very illustrative example of the information gap on sub-standard areas is shown in the work of Taubenböck and Kraff (2013), where different estimations of the population size of Dharavi (large slum in Mumbai) are contrasted, ranging from approx. 300,000 to 900,000 inhabitants.

THE UTILITY OF REMOTE SENSING TO EXTRACT INFORMATION ON SUB-STANDARD AREAS

In the past decades remote sensing has increasingly become a valuable data source to support the planning and management of city development, in particular since the availability and easier access to VHR images. In India, for instance, many city government were able to purchase VHR images with JNNURM funding to initiate the generation of GIS base layers as a support for urban planning and management. VHR images namely help to extract information on highly compact built-up areas where small buildings are highly clustered. Image analysis (e.g. image segmentation) allows researchers to extract areas of roof objects, here called buildings footprints. Furthermore, image segmentation makes it possible, depending on the parameter setting in an object oriented analysis (OOA), to extract homogenous neighbourhoods, here called homogenous urban patches (HUPs) in reference to the work of Liu, et al. (2006). Such HUPs represent larger areas of homogenous textural and spectral characteristics.

Many on-going and past studies have focused on extracting building footprints. For example the PanTex algorithm (Pesaresi, Gerhardinger, & Kayitakire, 2008) allows using the co-occurrence matrix (GLCM) to extract building footprints that are in clear contrast with their surroundings. GLCM are

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textural statistics, including e.g. entropy, contrast and variance within a given window size (Haralick, Shanmugam, & Dinstein, 1973). While presently two major global urban footprint layers are under development one using SAR data (Esch, Thiel, Schenk, A. Roth, & A. Müller, 2010) and one using optical data (Pesaresi & Halkia, 2012).

Spatial metrics have been increasingly used in the past years to analyse the urban morphology, showing their potential for quantifying physical and morphological characteristics of the urban landscape (e.g. Baud et al., 2010; Herold, Couclelis, & Clarke, 2005). In a recent publication Taubenböck and Kraff (2013) analysed urban morphological parameters for the city of Mumbai focusing on building density, building sizes and building height, building distance and heterogeneity index at block level. Within their research they analysed three different slum areas, Santosh Nagar, Bharat Nagar and Dharavi. They concluded that slums show in general very high building densities (compared to formal areas), homogeneity of building sizes, homogeneous building height of 1-2 stories and very clustered buildings (low distance). However they also stressed that the three slum areas are not that homogenous, showing variation in their morphological characteristics. In particular the slum area of Dharavi has a higher heterogeneity index compared to the two other slum areas.

RESEARCH FOCUS

The main focus of this paper is to analyse whether meaningful information about the location and physical characteristics of sub-standard areas in Mumbai can be extracted from very-high resolution (VHR) imagery using digital image analysis. The newly available 8-Band images of WorldView-2 have possibly an interesting capability to deliver information on sub-standard urban areas due to the high spatial and spectral resolution. As concluded in our previous paper on Delhi (Baud et al. 2010), deprived areas are characterized by small building sizes, high densities and organic layout pattern. These morphological characteristics can be used as a proxies to extract them. For the present study we focus whether such morphological characteristics can be automatically extracted from an image which would allow us to distinguish clustering of different types of sub-standard areas. Thus the main research question for this paper are:
- What are the quantifiable differences between sub-standard areas and formal areas using VHR imagery?
- What physical characteristics are useful for extracting the major types of sub-standard areas in a VHR image?
- How heterogeneous are the rather large health wards in terms of sub-standard areas?

SUB-STANDARD AREAS IN MUMBAI A TYPOLOGY

The variety of sub-standard areas in Mumbai range from encroachments along physical infrastructure (see e.g. fig. 2) such as highways, pipelines or the airport area to rather regular and well maintained areas with concrete houses of 2-3 storeys with proper paths and open spaces between the houses as well as access to formal economic activities. Encroachments are often temporary areas displaying very high densities and poor housing structures and lack any access to basic service provision. A second type of sub-standard settlement are long-established settlements with extremely high densities and rather small houses and narrow lanes between the houses, which quite often also lack access to basic services such as piped water or a closed drainage system. The third type of settlement has slightly larger houses of 1-2 storeys, though often in irregular arrangements, with somewhat larger paths

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between the houses, though still very little space between the houses. Despite the high density and the little open space, houses and spaces are rather clean and well maintained. Often, some basic infrastructure is present. A fourth type consists of a gradual transition to sub-standard areas with a mix of smaller and larger houses, often also linked to economic production such as making garments or recycling waste. The fifth type - upper end - of sub-standard areas consists of larger buildings, often 2-3 storeys, and some wider paths and streets as well as open spaces within the settlements. These areas are mostly well established, have access to the main basic infrastructure and have existed already for a long time. Accordingly, as found by Taubenböck and Kraff (2013) and the report 'Beyond Typologies' by a large team of Indian researchers (Gupte, Shetty, Mishra, & Mayadeo, 2010), sub-standard areas in Mumbai are very diverse in terms of their physical characteristics (e.g. densities) (see fig. 1 and 2).
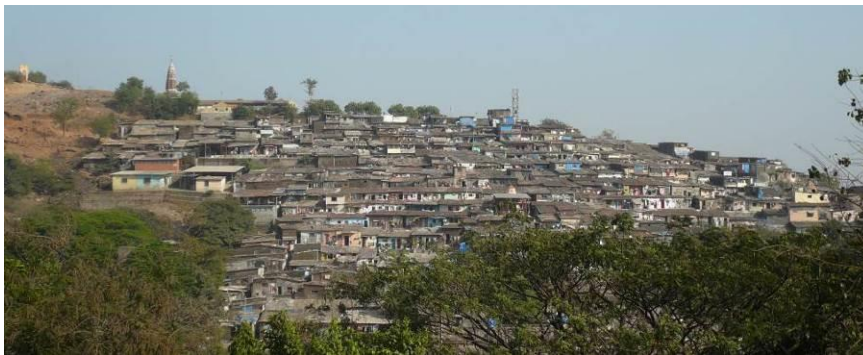
[fig. 1] Sub-standard area in Mumbai climbing up a steep slope

[fig. 2] Sub-standard area in Mumbai allowing a road

PHYSICAL CHARACTERISTICS OF SUB-STANDARD AREAS IN MUMBAI – A TYPOLOGY

The diversity of sub-standard areas in Mumbai has been classified into five types of sub-standard areas using fieldwork (survey and ground photos) and discussions with local experts. This makes it possible to compare their morphological characteristics with information extracted from image analysis, texture analysis and spatial metrics. Besides the five types of sub-standard classes one standard class was extracted to see whether sub-standard areas differ significantly from this class. The standard class named formal areas is also rather heterogeneous but all formal areas are of relatively regular building layout and larger building sizes (ranging from medium sized buildings to apartment blocks).

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[tab. 1] Typology of sub-standard areas

No.	Classification of deprived areas	N	Size of buildings footprints	Density of area	Pattern of area	Ground photo of sample area
1	Slum pocket	13	Small	High	Organic	
2	Slum area, small buildings	21	Small	High	Organic	
3	Slum area, mix small/large buildings	11	Mix	High	Diverse (some areas with and some without structure)	
4	Slum area, larger buildings and chawls	8	Medium	High	Larger buildings give somewhat more structure	
5	Basic formal	6	Medium	High	Some structure	
6	Formal areas	21	Large	Medium – low	Well structured	

As concluded also in our previous paper on Delhi (Baud et al., 2010) the main characteristics of sub-standard areas are commonly related to:

- Size (small building sizes)

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- Density (high density built-up neighbourhoods)
- Layout pattern (rather organic layout patterns)
- And locational characteristics (e.g. proximity to transport infrastructure).

Also for the case of Mumbai these morphological characteristics have the potential to describe sub-standard areas and quantify difference between types of sub-standard areas.
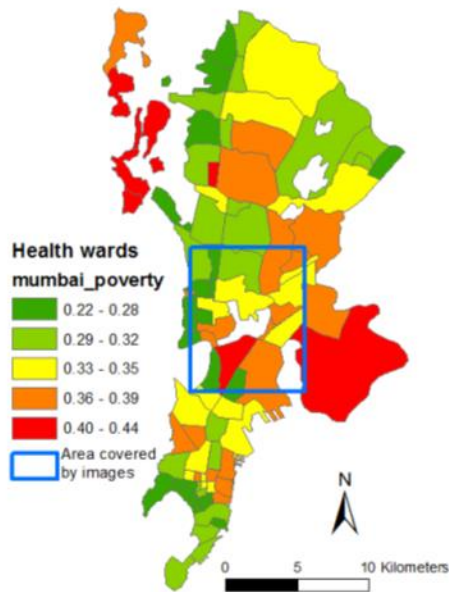

AVAILABLE DATA SET FOR THIS RESEARCH

The study area is the agglomeration of Mumbai. For this research 6 scenes of WoldView-2 images (pan:0.5 and MS: 2 m) acquired in 2009 have been provided by DigitalGlobe. The images have an improved spectral resolution of 8 multi-spectral band increasing the spectral separability of land cover classes. The scenes have been combined into one image mosaic covering a part of the city of Mumbai (fig.3).

[fig. 3] Image mosaic (radiometric corrected) of the 6 scenes, covering a central part of Mumbai

Besides image data, several GIS layers were available for the research, including health ward boundaries, road and railroad networks. Only 15 health wards are completely or almost completely covered by the WorldView-2 images. But the covered area has a good mix of the full range of the index of multiple deprivation categories (see fig. 4) produced in the previous research on poverty mapping in Indian megacities (cf. Baud et al. 2008 and 2009). For the city of Mumbai, the index ranges from 0.22 for the least deprived wards up to 0.44 for the most deprived wards.

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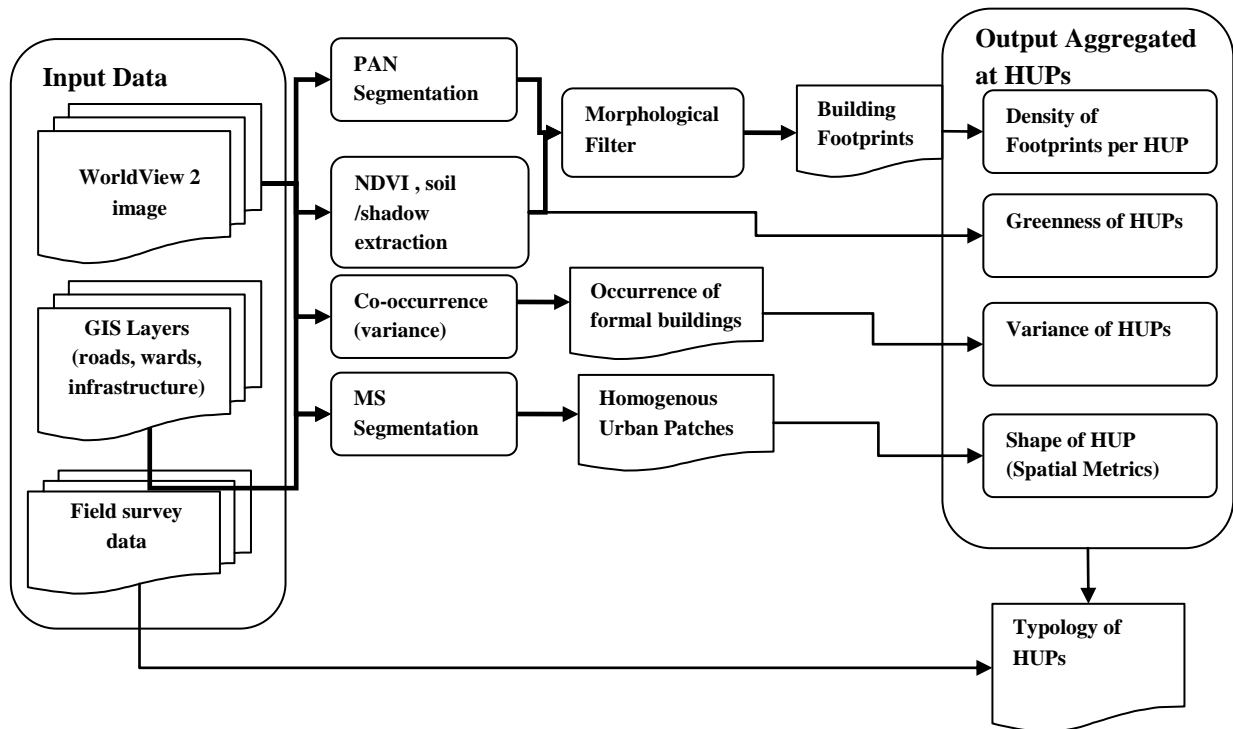
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[fig. 4] Health wards of Mumbai, classified by levels of deprivation (high values indicating high deprivation)

METHODOLOGY

The procedure of extracting HUP patches consists of several steps, illustrated in detail in fig. 5. First, in order to extract buildings footprints image segmentation of the panchromatic images was performed. Then the result was improved by using the NDVI (Normalized Difference Vegetation Index) and an extraction of soil and shadow areas, followed by applying morphological filters. The result, namely the extracted building footprints, serves as an input for calculating the morphological characteristics of homogenous areas (HUPs). The HUPs have been extracted by image segmentation in an object oriented image analysis (OOA) process using also the roads and railroads as additional layers. The outcome, the HUPs, represent small neighbourhoods of homogenous textural characteristics. In order to support the segmentation process and verify the outcome, field data was collected in February 2011 and March 2013. The choice of sites for data collection was guided by the information demand of the segmentation process. The fieldwork consisted of visiting the sites, recording the XY co-ordinates of the approximate location of the centre of the settlement, taking photographs of the main morphological characteristics and filling out a structured survey form based on site observations and short interviews with settlement residents. In the first fieldwork period, about 50 sites were visited, covering different types of sub-standard settlements. In the second fieldwork period in 2013, ground-truthing of 10 additional sites was done, mainly used for fine-tuning the classification criteria as well as the segmentation process.

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[fig. 5] Overview of Methodology

PART 1: PRE-PROCESSING AND FOOTPRINT EXTRACTION

The images underwent a radiometric correction by converting the relative radiance into absolute radiance using the meta-data file of the images. As a next step an image mosaic of the 6 scenes was constructed. In a final step the images have been pan-sharpened using the Ehlers transformation, which was recommended by Yuhendra, Alimuddin, Sumantyo, and Kuze (2012) as very suitable for World-View2 images.

The panchromatic (PAN) image was used to perform an image segmentation, of which the result was combined with the extracted NDVI, the extracted soil brightness index as well as shadow index. In an iterative process all features which are not a building were removed to finally obtain a building footprint map. The final result was improved by using morphological filters (dilation and erosion), which better approximates the building footprints. The resulting footprints are representing the built-up pattern of the city (fig. 6). In general the footprints indicate well the shape of larger buildings, but in areas of highly clustered buildings (typical for sub-standard areas) the extracted footprints do not represent individual buildings but are larger clusters of adjacent buildings.

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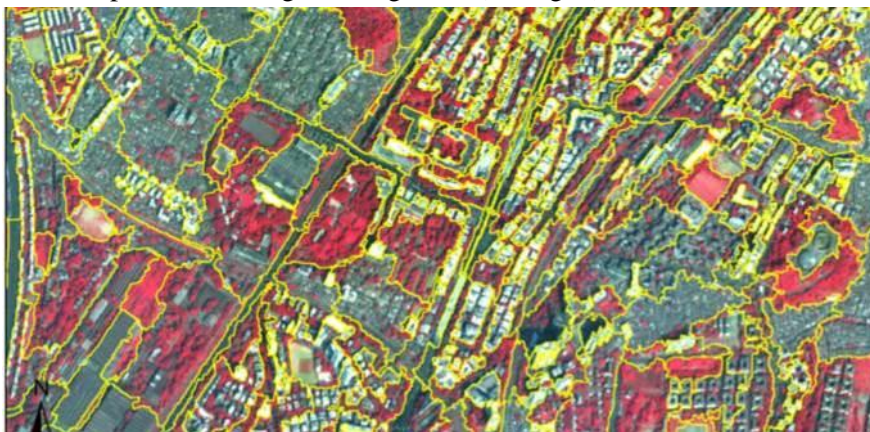**Enschede 12 - 14th September 2013**

[fig. 6] Example of extracted building footprints: grey areas represent buildings footprint, on the back the image mosaic (FCC)

The main preliminary conclusion that we can draw from this segmentation process is that building footprints can be approximated at city level, which allows to use this layer as input for analysing morphological aspects like densities while building sizes cannot be extracted.

PART 2: EXTRACTION OF HOMOGENOUS URBAN PATCHES (HUPS)

In order to aggregate morphological characteristics at a level below large administrative units like health wards, HUPs are extracted by image segmentation with the focus to extract homogenous areas, that is to say neighbourhoods that have relative homogenous (texture) structure. The purpose for using HUPs is to dis-aggregate the morphological characteristics at this level. This assumes that the HUPs are neighbourhoods of a similar morphological setup. In order to extract HUPs the multispectral WorldView-2 images were used in an OOA environment. We used the scale parameter of 200 for the segmentation process together with a high weight on texture characteristics as well as including the roads and railroads into the processing. This combination resulted in areas of similar morphological characteristics. In particular, large sub-standard areas tend to have larger HUPs while some of the formal areas are smaller in size, due to the texture change of the surrounding vegetation areas which causes separation of neighbouring areas (see fig. 7).

[fig. 7] Extracted homogenous urban patches (HUPs) in yellow

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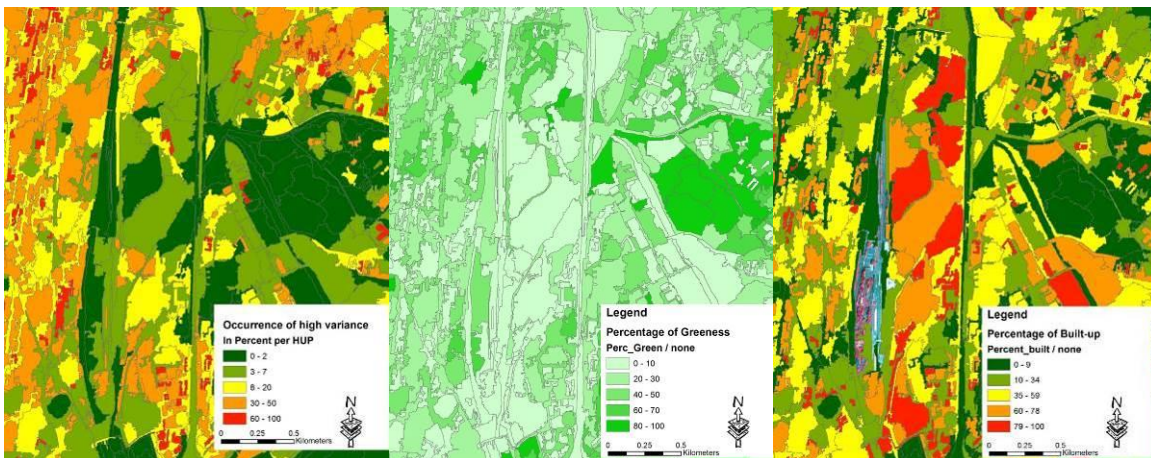Enschede 12 - 14th September 2013

PART 3: EXTRACTION OF MORPHOLOGICAL CHARACTERISTICS

In a next step the variance of a co-occurrence matrix (GLCM) was used to extract building footprints that show a clear contrast with their surroundings. Such areas with high variance values represents larger buildings commonly buildings in formal (standard) areas. This allows to indicate HUPs with low occurrence of high variance values, these HUPs have a high probability (when being also densely built-up) to be sub-standard areas. Accordingly, variance of the GLCM is an easily implemented proxy to extract sub-standard areas in combination with built-up density (the combination with built-up density is necessary to remove non-built up areas that also might have low variance values). Thus also the built-up density per HUP is calculated by dividing the footprint area by the HUP area (fig. 9).
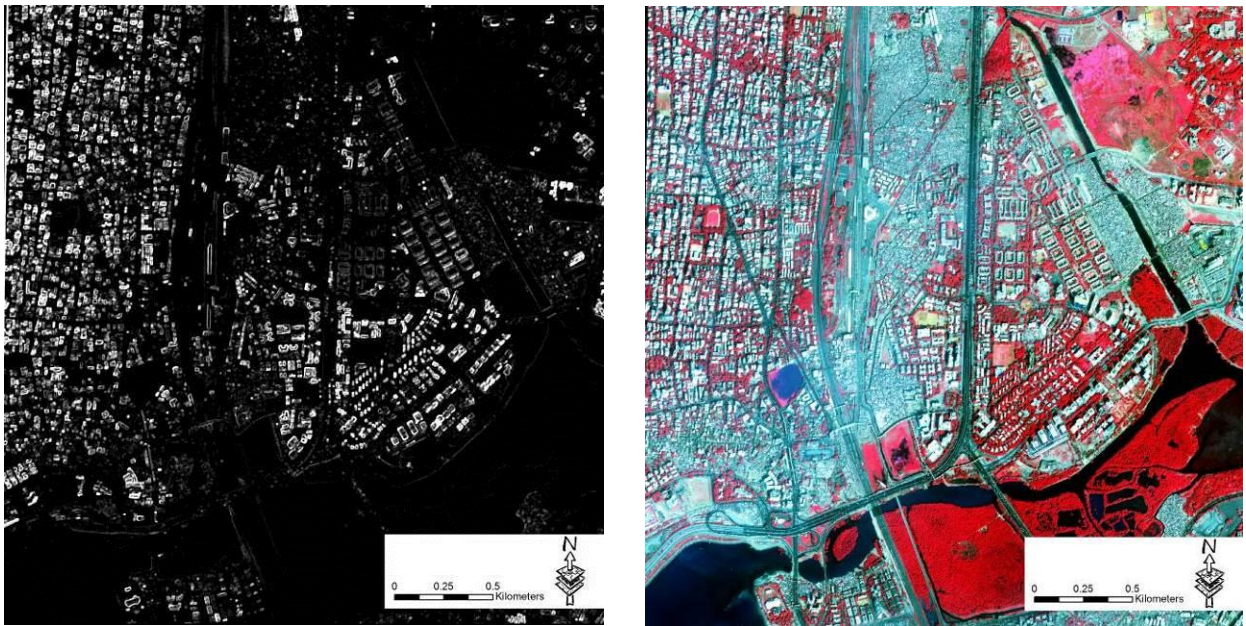
[fig. 8] Co-occurrence matrix (GLCM), variance: light colour indicating areas of high variance (left) WorldView-2 image of the same area (right)

Both built-up density as well as the density of green areas was calculated for all HUPs. The green areas are extracted from the NDVI and are divided by the total area of the HUP (fig. 9).


[fig. 9] Variance (left), % of Greenness (middle) and % built-up aggregated at HUPs level

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In order to quantify aspects of the HUP shape two spatial metrics have been used, namely the Radius of Gyration (GYRATE) and the Perimeter-Area Ratio (PARA). GYRATE equals the mean distance (m) between each cell in the patch and the patch centroid, while the PARA equals the ratio of the patch perimeter (m) to area (m^2), measuring shape complexity in a simple way. The output gives a value for each HUP, where larger values indicate less compactness and high complexity.
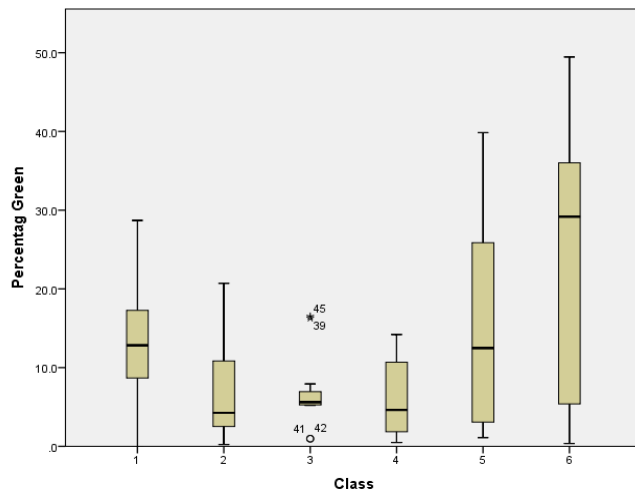
RESULTS AND DISCUSSION

The variance of co-occurrence matrix (GLCM) allows us to clearly separate sub-standard areas from formal built-up areas (fig.10). In the data set there is only one outlier (sample area No. 59) which is a sub-standard basic formal area which falls into a HUP containing also building blocks. Also HUPs of basic formal areas (class 5) have on average more occurrences of high variance values. For the percentage of built-up areas the result is less distinct. Formal areas (class 6) have the lowest densities, surprisingly followed by class 1 (slum pockets) which are often located close to urban infrastructure and formal areas with a higher abundance of vegetation, and therefore surrounded by vegetation in the HUP as well as some very small slum pockets are a mix of slums and formal areas. The 3rd lowest densities are found in the basic formal areas, where often some basic open spaces are provided. Class 2, 3 and 4 have the highest densities. A similar picture is given by the percentage of green areas. Here the high amount of green areas of class 1 is confirmed, while particular formal areas have a large range of greenness, showing also some formal areas with very little green spaces. This is often caused by clustering the adjacent vegetation areas into a different HUP (caused by rapid texture change between a formal built-up area and an area of vegetation).
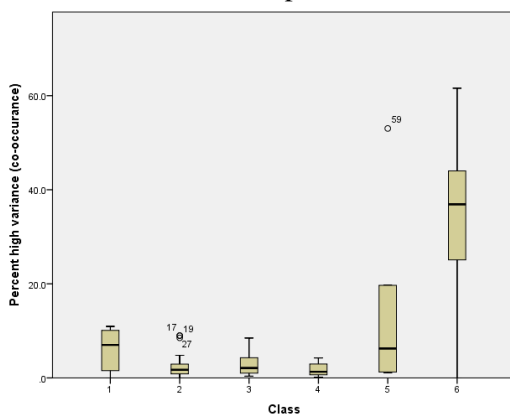
[fig. 10] Variance at HUPs level for the different sub-standard and standard classes
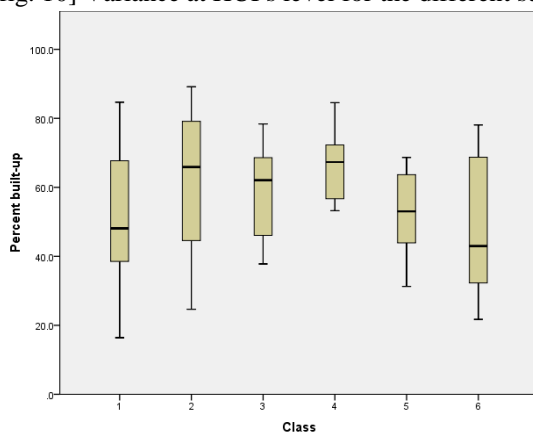

[fig. 11] Percentage of built-up areas at HUP level for the different sub-standard and standard classes

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[fig. 12] Percentage of Green areas at HUP level for the different sub-standard and standard classes

In order to see whether the mean values per HUP of the percentage of built-up, greenness, high variance, as well as GYRATE and PARA could be used to differentiate between types of sub-standard areas all five proxies of sub-standard areas are combined into a chart (fig. 13). The figure shows that formal and slum pockets have similar PARA values (values of PARA and GYRATE have been normalized to fit the range from 0 to 100) which indicates that HUPs' shape of the two classes are rather complex. The complexity of shape of formal areas are again caused by the textural changes while in case of slum pockets these areas are often indeed of very irregular shape. The proxies greenness, built-up, variance, GYRATE and PARA show difference for the six classes, such proxies could allow classifying an image. E.g. slum pockets have in general low variance values and irregular shapes and have often some small green areas at the edge of the HUP, while basic formal areas have higher variance but a similar amount of green areas and percentage of built-up.
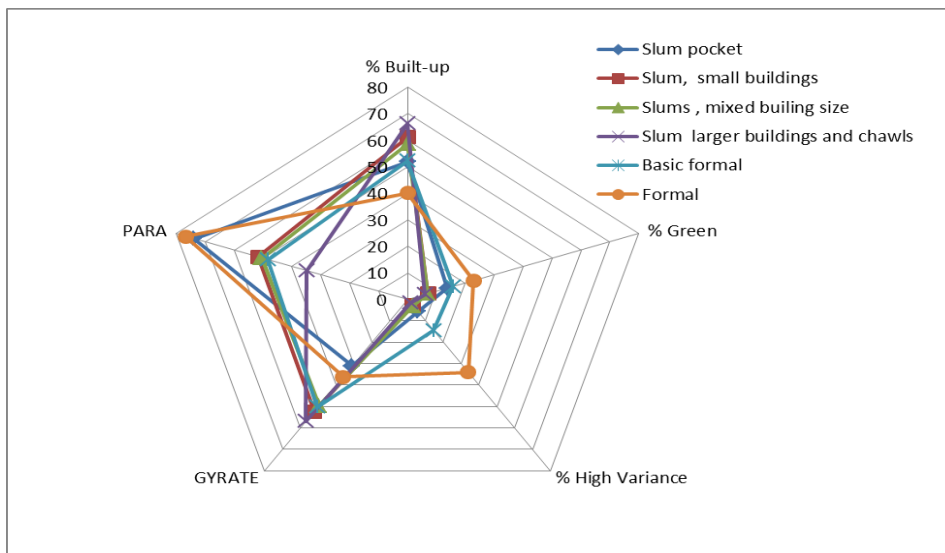
[fig. 13] Proxies of sub-standard areas (Mean per HUPs)

In order to illustrate heterogeneity of the rather large health wards, an example of one ward is displayed in fig. 14. The ward includes the large and well-known slum of Dharavi. The calculated multiple deprivation index (0.4) indicates this ward as one of the most deprived in Mumbai (maximum

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multiple deprivation index is 0.44 in Mumbai). Fig. 14 shows that most of the ward is not covered by formal buildings (displayed by the low level of variance), although in the North-West an area of formal buildings can be found as well as within the sub-standard areas small HUPs of formal buildings exist (indicated by orange-red colours). Further the amount of greenness indicates that are large part of the ward is covered by vegetation (Dharavi Mangroves) but also in-between very densely built-up areas green patches are visible. The built-up density shows high levels of variation; with the slum area of Dharavi in general producing high-density values as well as the Northern part being dominated by multi-story buildings and construction activities (at the moment the image was acquired), while lower densities are found in the other area of the ward. The result shows a high level of heterogeneity within one of the most deprived wards, which hosts large areas of sub-standard housing as well as formal areas and large areas of green space (e.g. the Mahim Nature Park).
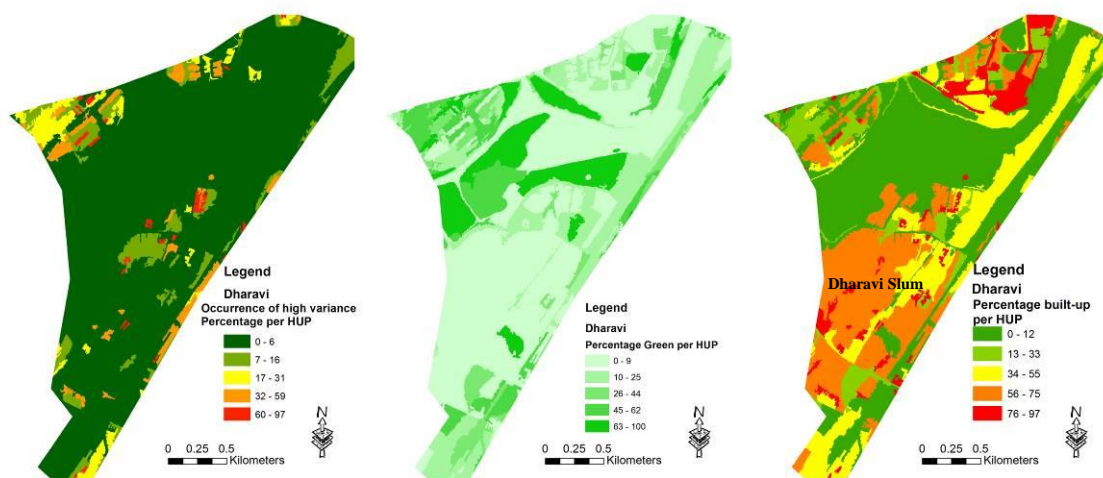
[fig. 13] Proxies of sub-standard areas (Mean per HUPs) for Dharavi ward (Multiple Deprivation Index of 0.4)

CONCLUSION

The aim of this paper was to find answers to three research question. First, to see whether quantifiable differences between sub-standard areas and formal can be extracted in a VHR image. Second, to find physical characteristics that are useful for extracting types of sub-standard areas in an image. And third, to analyse the heterogeneity of the rather large health wards in terms of sub-standard areas. The main frame was to use image analysis to allow rapid information extraction compared to visual image interpretation used in our previous work on Delhi (Baud et al., 2010).

Q1 In order to have a very disaggregated analysis level homogenous urban patches HUPs have been extracted using texture as well as the transport network in an image segmentation process. Preliminary results have shown that the variance of a co-occurrence matrix (GLCM) allows us to extract HUP that are dominated by formal buildings with having high variance values (caused by the contrast of the buildings and their surroundings). Thus this measure allows us to establish HUPs that represent formal (standard) urban morphologies, while HUPs with low variance values are potentially areas of sub-standard development, given they are also densely built-up. Variance further allows to analyse differences between the types of sub-standard areas, where e.g. basic formal areas and slum pockets (influenced by adjacent formal buildings) tend to have higher variance values compared to other types of sub-standard areas.

Q2: The major morphological characteristics used to describe the typology of sub-standard areas are percentage of built-up area and greenness, variance of the GLCM as well as GYRATE and PARA,

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which together characterize the HUPs' shape, complexity and built-up structure. The rather preliminary results presented in this paper show variation of these morphological characteristics between the different types of sub-standard areas. Whether these differences can be used to automatically distinguish types of sub-standard areas in an image at sufficient high accuracy will be explored in an upcoming study.

Q3 Using the example of one of the most deprived wards in Mumbai (Dharavi) inner-ward heterogeneity was analysed. Results show that aggregation at this level conceals essential information on diversity. This suggests that health wards are diverse units in terms of the urban morphology, combining formal and different types of sub-standard areas, with large variation of densities. Thus using data for planning purposes at such an aggregation level might conceal essential information on the urban morphology.

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